

## ECOLOGICAL BENEFITS OF RIPARIAN REFORESTATION IN URBAN WATERSHEDS: STUDY DESIGN AND PRELIMINARY RESULTS

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**Abstract.** Riparian forest restoration has become a major focus of watershed initiatives to improve degraded stream ecosystems. In urban watersheds, however, the ability of riparian forests to improve stream ecosystems may be diminished due to widespread, upland disturbance. This paper presents the methodology and some preliminary results from the first year of fieldwork on a 3-year project designed to assess the ecological benefits of riparian reforestation in urban watersheds. The study is based on an integrated, multidisciplinary sampling of physical, chemical, and biological attributes at forested and non-forested sections of 12 streams with different amounts of urban development within their watersheds. Restored sections of three streams are also being monitored over the 3-year duration of the project. Sampling and analysis will continue through December 2000.

### 1. Introduction

Urban streams are arguably the most extensively degraded and disturbed aquatic systems in North America (Schueler 1987). Impermeable rooftops and pavement together with a concentration of waste discharges and non-point pollution affect the hydrology, geomorphology, water quality, and aquatic ecology of urban streams. Typical urban effects include increased overland flow and storm runoff volume, increased peak flows, decreased groundwater flow, increased suspended particulates and sedimentation of fine particles, increased channel erosion, and increased inputs of nutrients and toxic substances. The severity of urbanization impacts on aquatic systems has created an urgency for the restoration and management of urban streams and watersheds.

Riparian forests have been shown to be very important to stream ecosystems as regulators of hydrologic and nutrient fluxes, light and temperature regimes, physical habitat, and food/energy base (Gregory et al. 1991, Sweeney 1992). The restoration of riparian forests has subsequently become a major focus of watershed initiatives to improve degraded stream ecosystems. In the mid-Atlantic region, the Chesapeake Bay Program recently announced a goal of restoring 3,234 km of riparian forest by the year 2010, and in southeast Pennsylvania the

William Penn Foundation has provided funding for the restoration of up to 80 km of riparian forest in the Schuylkill River watershed.

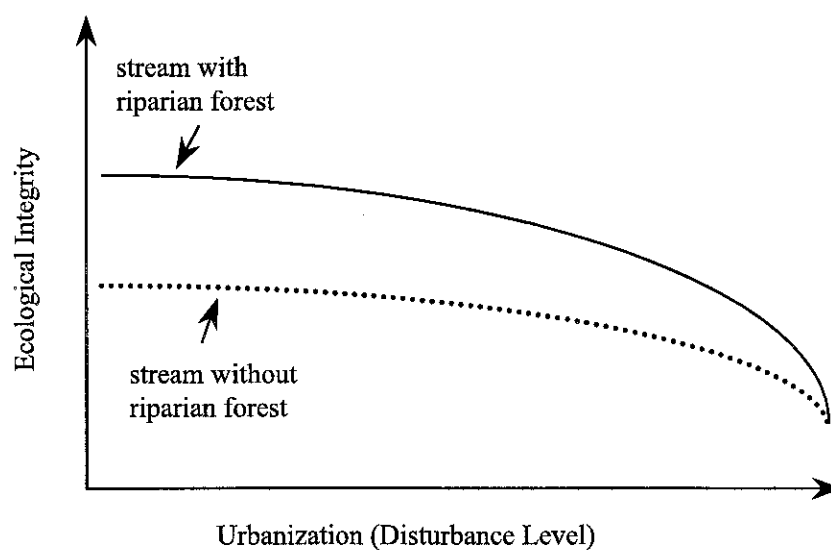
In urban watersheds, however, the long-term ecological benefits of riparian restoration may be diminished due to widespread hydrologic and biogeochemical disturbance within the watershed. Without a better understanding of how riparian forests benefit streams in urban watersheds, there is a real danger of wasting effort on techniques that are inappropriate to local situations. In highly disturbed watersheds, additional improvements including stormwater and/or water quality management may be required before stream ecosystems can be successfully restored.

This paper presents the methodology and some preliminary results for a three-year research project designed to assess the influence of riparian forests on stream ecosystems in urban watersheds. Our basic hypothesis is that the benefits of riparian forests to stream ecosystems decrease with increasing urban development within the watershed. This relationship is illustrated in Figure 1. In the context of riparian restoration, the curves in Figure 1 represent pre- and post-restoration endpoints, and the vertical distance between curves represents the potential ecological benefit of restoration. The objectives of the project are: 1) to understand the influence of riparian forests on the structure, function, and dynamics of low-order stream ecosystems, 2) to determine relationships between ecosystem attributes and urban development for streams with and without riparian forests, 3) to develop models for prioritizing riparian reforestation efforts based on expected ecological benefits, and 4) to measure and evaluate the rates at which various ecosystem attributes respond to riparian reforestation.

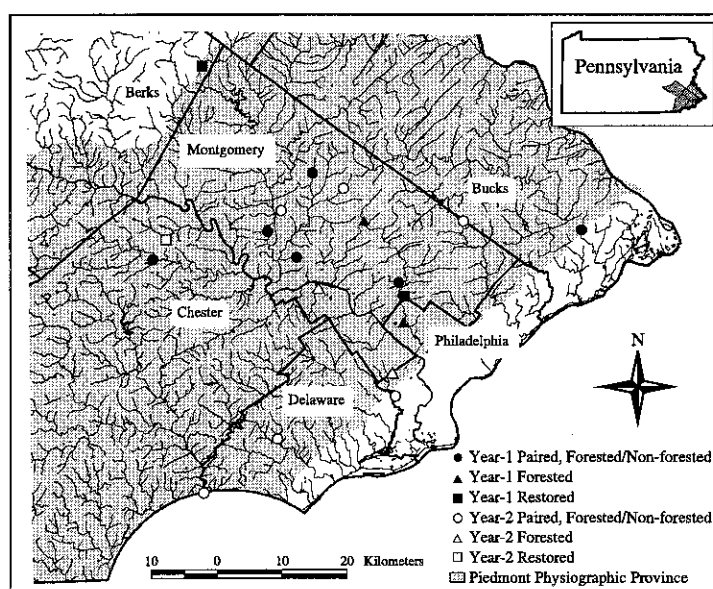
## 2. Study Area

The study includes 19 first- through third-order streams in the Piedmont portion of the Delaware River watershed in southeastern Pennsylvania. Several study streams are within the Philadelphia metropolitan region (Figure 2). Developed and residential lands in the Philadelphia metropolitan region increased by 30% from 1970 to 1990 (DVRPC 1994), and are projected to increase by another 47% from 1990 to 2020.

Southeastern Pennsylvania is comprised of broad, rolling hills in the Piedmont Uplands of Chester, Delaware, and northern Philadelphia counties, and less steep, rolling hills in the Piedmont Lowlands of Montgomery, Bucks, and Berks counties. The Uplands occur mainly on metamorphic schists, and the Lowlands on sandstone and shale. Small areas of limestone and dolomite occur in southern Montgomery county. Soils are primarily alfisols and well developed ultisols (Ciolkosz et al. 1989). The region supports a fragmented, mixed-hardwood deciduous forest with large areas cleared for agricultural and urban development. Precipitation averages about 110 cm per year.



**Figure 1.** Hypothesized relationship between stream ecological integrity, riparian forests, and urban development within watersheds.



**Figure 2.** Site location map showing year-1 and year-2 study sites.

### 3. Experimental Design

The experimental design is based on comparisons of ecosystem structure and function in forested and non-forested sections of 12 streams with different amounts of urban development within their watersheds. Each of these sites is comprised of nearly contiguous, forested and non-forested stream reaches with no major tributary inputs or other disturbances between reaches. Throughout the remainder of this paper, these 12 sites are referred to as paired-reach sites. Because of difficulty in locating suitable paired-reach sites in highly urban watersheds, the experimental design also includes sampling of forested sections of four streams in highly urban watersheds. These sites are referred to as unpaired-forested sites, and are included to provide information about the ability of riparian forests to compensate for watershed-scale disturbance, i.e., if an urban stream with a mature riparian forest is in poor ecological condition, it suggests that the forest does not fully compensate for high levels of upland disturbance within the watershed.

The experimental design also includes detailed monitoring of restored sections of three streams over the three-year duration of the project. Restoration activities at these sites include the removal of invasive exotic vegetation, bank re-grading, installation of fiber logs and mats to stabilize stream banks, and planting native vegetation along one or both streambanks. Two of the paired-reach sites will also be monitored over the three-year duration of the project to establish a baseline by which changes in restored reaches can be evaluated.

The structure and function of each study reach (two reaches per paired-reach site; one reach per unpaired-forested site; one reach per restored site) will be assessed through an integrated, multidisciplinary sampling of channel geomorphology, bed and bank erosion, water chemistry and temperature, food web linkages, benthic algae, benthic macroinvertebrates, and fish. Physiographic and stream size differences among study sites were minimized by including only first through third order streams on the Piedmont plateau north and west of Philadelphia, Pennsylvania. Sites influenced by dams, bridges, ponds, wastewater discharges, cattle grazing, construction projects, and other site-specific features were also not included in the study to reduce variability among study sites.

### 4. Methods and Preliminary Results

A search for study sites was conducted during the spring of 1998 that included studies of aerial photographs, interviews with knowledgeable persons, and visual observation of nearly all first- to third-order streams in the Piedmont area north and west of Philadelphia. Six paired-reach sites, two unpaired-forested sites, and two restored sites were selected for the year-1 field season. Year-1 study sites range from first to third order streams, and from 0 to 70% urban development within their watersheds (Figure 2, Table I).

Year 2 sites were selected during the spring of 1999, and year 2 fieldwork will be completed during the summer and fall of 1999. Monitoring at restoration sites and baseline reference sites will continue into the year 2000. The following sections present a more detailed discussion of experimental methods and some preliminary results for year-1 study sites.

#### 4.1 SITE CHARACTERIZATION

Each stream reach was characterized in terms of watershed physiography, urban development within the watershed, hydrology, physical habitat, and riparian vegetation. Watershed physiography and urban development were determined using geographic information system software and digital spatial datasets for soils (NRDC), surface geology (USGS), ecoregions (USEPA), and land-cover (EROS Data Center 1991–93). Urban development within each watershed was expressed as the percent of total watershed area classified as “developed” in the EROS land-cover dataset. Additional indices of urban development will be evaluated in later analyses.

Historical streamflow data are not available for any of the study sites. Flow duration curves for each site will be estimated using a regional regression approach based on watershed characteristics, land-cover, and streamflow data from neighboring gaged watersheds. Peak stormwater flows will be estimated at each site using a stormwater flow model. Staff gages have been installed at each site, and point measurements of discharge will be made over the three-year duration of the project.

Physical habitat was characterized at each study reach by constructing detailed maps of habitat types, measuring the areal extent of cover including undercut banks, rootwads, and overhanging vegetation, and documenting the number and physical dimensions of large woody debris within each reach. Measurements of flow velocity, flow depth, channel width, substrate size distributions (Wolman 1954), substrate compaction, and substrate embeddedness were also made at six transects within each reach.

Riparian trees, shrubs, and herbaceous plants were characterized at three transects along each reach using nested 100, 25, and 1 square-meter quadrats, respectively, at each transect. Measurements included species richness, basal area, canopy density (trees), and percent cover (shrubs).

#### 4.2 STREAM GEOMORPHOLOGY

All experimental reaches are approximately 20 channel-widths in length, include at least 5 channel storage features, and begin and end at similar bed features. Longitudinal profiles for each reach were surveyed using a laser-level and used to determine stream gradient, water surface slopes, and the frequency, heterogeneity, and complexity of bed features. Channel cross-sectional profiles were surveyed at

**Table I**  
Summary of watershed characteristics and preliminary ecological assessment of year-1 research sites.

Stream Name	Riparian Vegetation	Basin Area (km <sup>2</sup> )	Land Cover		Geomorphology		Water Chemistry			Algae		Fish				
			Urban (%)	Forest (%)	Agric. (%)	Mean Bankfull x-Section (m <sup>2</sup> )	Mean Bed Material (mm)	DIN (μgN/L)	SRP (μg/L)	N:P (molar)	Chl- <i>a</i> (μg/cm <sup>2</sup> )	Total Taxa	Shannon Weiner Index	Total Taxa	Shannon Weiner Index	
Paired-reach sites																
Queen Anne	forest	15.3	60	25	11	3.9	44	931	12	171	8.6	111	3.9	25.8	19	1.9
Queen Anne	non-forest	15.8	60	25	11	2.6	31	857	11	172	74.2	99	3.6	31.4	18	2.1
Eagleville	forest	1.1	51	25	24	1.9	55	1,253	16	173	3.0	53	2.9	51.6	1	0.2
Eagleville	non-forest	0.8	54	21	24	1.7	61	604	4	334	232.6	53	2.8	51.3	2	0.7
W. Br. Skippack	forest	4.0	27	11	62	2.8	23	263	28	20	3.3	72	3.5	19.5	16	1.6
W. Br. Skippack	non-forest	3.4	30	10	60	2.0	25	197	21	21	14.5	59	3.1	42.3	12	1.2
Donny Brook	forest	3.5	32	26	42	2.1	34	451	24	42	2.8	80	3.3	42.5	8	1.2
Donny Brook	non-forest	2.9	25	26	49	0.8	64	674	12	124	6.8	58	2.9	55.2	na	na
Lorraine	forest	3.2	23	57	20	1.3	23	na	na	na	na	na	na	na	na	na
Lorraine	non-forest	2.0	28	57	14	0.6	37	12	9	9	5.8	62	2.9	51.7	na	na
Beaver	forest	11.6	0	70	29	2.3	98	943	24	89	1.6	74	3.2	41.4	14	1.8
Beaver	non-forest	13.0	0	71	28	2.0	75	937	21	99	4.4	67	2.5	51.4	17	1.9
Unpaired sites																
Wises Mill	forest	0.9	70	20	10	2.7	127	4,369	50	195	2.0	58	2.8	55.0	0	0
Wissahickon	forest	11.9	55	27	17	3.7	75	283	84	7	na	95	3.4	41.9	12	1.5
Restored sites																
Paper Mill	non-forest	6.1	64	29	6	2.2	63	454	6	167	162.0	57	3.2	41.3	9	1.1
Trib., Perkiomen	non-forest	11.8	0	62	37	1.6	61	3,276	15	500	30.5	75	3.6	28.6	18	2.3

na = data not available

five locations along each reach and used to quantify channel dimensions and floodplain features. One cross-section per reach was marked with steel rebar 1.3 m in length and established as a permanent reference site for future monitoring.

Preliminary results suggest that at all levels of urbanization, forested stream channels are as much as 2.5 times wider than non-forested channels, and cross-sectional areas of flow in forested channels are 1.1 to 2.7 times larger than in non-forested channels (Table I). These results are supported by other studies which show that small, forested stream reaches tend to be wider and shallower than contiguous non-forested, grass-bordered reaches (Trimble 1997, Davies-Colley 1997, Hession et al. 1998). Future analyses include quantifying how observed channel differences influence stream ecosystem structure and function in urban versus non-urban streams. Geomorphological data will also be used in the development and calibration of sediment transport models, to evaluate channel complexity, and to quantify variability in physical habitat.

#### 4.3 BED MATERIAL, BANK EROSION, AND SEDIMENT TRANSPORT

The grain size distribution of bed materials at each reach were determined using a variation of the Wolman method based on a sample of at least 200 gravel particles (Wolman 1954, Rice and Church 1997). Bank erosion rates during the 3-year study period will be estimated at selected reaches by annually re-surveying permanent cross-sections. Longer term, time-averaged rates of bank erosion will be estimated by identifying and dating point bar deposits at migrating bends (Everitt 1968, Nanson 1980). The magnitude and frequency of bedload transport are important geomorphic and ecological processes that could vary systematically with urbanization and riparian vegetation. Water level recorders and bedload traps have been installed in the forested and non-forested reaches at Beaver Run in order to calibrate models of bedload transport and initiation of sediment motion for the study area.

Preliminary data suggest that bed material grain sizes do not appear to be related to riparian vegetation or to the extent of urbanization. The mean grain diameters are all in the gravel size range as shown in Table I.

#### 4.4 NUTRIENT BIOGEOCHEMICAL CYCLING

Detailed nutrient studies will be conducted at selected paired-reach sites to investigate how riparian zones influence nutrient dynamics in urban versus non-urban watersheds. Water samples will be collected from the top, bottom, and at specific points within each reach over a time period proportional to the residence time of the water. Samples will be analyzed for dissolved and particulate nitrogen, carbon, phosphorus, total suspended matter, total alkalinity and hardness, dissolved chloride, and dissolved oxygen. In addition, the residence times of water in representative reaches will be determined by injecting a conservative tracer upstream

(sodium bromide), and sampling over time at the reach outlet to determine tracer breakthrough curves. Laboratory decomposition experiments will also be conducted using fresh benthic algal and leaf litter material to measure the release and re-incorporation rates for N and P. Sampling will be coordinated with other tasks and will focus on the spring, summer, and fall when biogeochemical processes are most active. Data-logging temperature probes (Onset Computer Corp.) have been installed at the upstream and downstream end of each reach and will provide hourly temperature data for a minimum of one year.

Water samples were collected at the downstream end of each year-1 reach four times between August 1998 and May 1999. Samples were analyzed for dissolved inorganic and organic nitrogen (dissolved  $\text{NO}_3^- + \text{NO}_2^-$ ,  $\text{NH}_3 + \text{NH}_4^+$ , and organic N), soluble reactive phosphorus (SRP), total phosphorus (TP), conductivity, pH, dissolved oxygen and temperature. Preliminary results indicate that non-forested reaches averaged 23% lower in dissolved inorganic nitrogen ( $\text{DIN} = \text{NO}_3^- + \text{NO}_2^- + \text{NH}_4^+$ ), and 90% lower in soluble reactive phosphorus (SRP) than forested reaches (Table I). The observed differences may be due to greater light availability in non-forested reaches resulting in increased immobilization of N and P by benthic algae. This is supported by benthic algal chlorophyll-*a* values 19 times higher in non-forested reaches than in forested reaches. Because samples were collected during the fall, the observed differences could also be related to reduced input of leaf litter in non-forested reaches. The N:P ratios in non-forest reaches were consistently higher than in forested reaches, and suggest a high potential that many reaches are phosphorus limited. Results from year-1 sites do not show a clear relationship between water quality and urban development.

#### 4.5 FOOD WEB STRUCTURE AND FUNCTION

Food web structure will be determined at each reach by comparing C and N isotopic ratios (i.e.,  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) between consumers and available food sources, allowing us to discern the origin of the food base (allochthonous versus autochthonous) for various consumer groups. Carbon stable isotopes will be used to trace the food sources of consumers, and N stable isotopes will be used to help place each consumer group at a specific trophic level (Lajtha and Michener 1994). The food sources considered are suspended particulate material, flocculated sediment, benthic algae, and allochthonous leaf litter. Consumer groups being considered are fish from three dominant feeding niches, and macroinvertebrates from three dominant functional feeding groups. The quality of the predominant food for major consumers will also be measured. The biochemical composition (total protein, lipid, carbohydrate, and crude fiber) of food sources will be used to assess changes in nutritional quality associated with the decomposition of organic matter. Food web samples were collected during the fall, winter, and spring 1998–1999 at each of the year-1 sites, and will continue at selected sites over the next two years.



#### 4.6 BENTHIC ALGAE

Benthic diatom community assemblages were determined for each reach based on four composite samples collected from each of the dominant stream habitat types. Composite samples were comprised of 15 to 25 subsamples and were collected in the early fall using USGS NAWQA Program protocols (Porter et al. 1993). Three hundred diatom valves from each composite sample were enumerated to species and used to establish community diversity metrics and relationships with habitat types and nutrient concentrations (Kutka and Richards 1996, Borchardt 1996). Estimates of algal biomass were made based on chlorophyll-a analysis of algal samples from artificial substrata. Algal samples were collected at the same time and locations as benthic macroinvertebrates to allow an integrated assessment of producer-consumer relationships. Additional analyses considering diatom ecological tolerance metrics will be considered after completing fieldwork at year-2 sites.

Preliminary results indicate that non-forested reaches have lower diversity (Shannon-Weiner index), lower evenness, and greater biomass than forested reaches (Table I). Principle components analysis showed that diatom assemblages may be related to urbanization, but results based on the year-1 data are not conclusive. The greater diversity in forested reaches may be due to increased microhabitat availability and light competition related to channel morphology and shading. Biomass estimates correlate closely with increased light availability in non-forested reaches, and could be associated with decreased DIN and SRP concentrations in these areas. Non-forested reaches also have elevated growth of filamentous green algae, perhaps a function of both light and streamflow characteristics.

#### 4.7 BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrate diversity, trophic composition, and standing crop were determined at each reach based on three replicate samples collected using a Surber Sampler. A stratified-random design was used to ensure similar macro-habitat types (i.e., riffles) were sampled. Organisms from each reach were identified to the lowest practical level, usually genus or species, and used to establish relationships with habitat, flow, and water chemistry characteristics. Macroinvertebrates were also classified in terms of functional feeding group (Merritt and Cummins 1996) and pollution tolerance (Hilsenhoff 1987). Community composition metrics such as the EPT index and Hilsenhoff's biotic index (HBI) will be calculated for each reach and used to evaluate relationships with habitat types, riparian vegetation, and urban development within each watershed. Macroinvertebrate sampling occurred once during early winter when larvae of most taxa are abundant in headwater streams.

Analysis of year-1 data is not complete, but we expect macroinvertebrate communities to be strongly influenced by the availability of different

microhabitats, flow regimes, and food availability. Shredders should be more abundant in forested reaches, and scrapers more dominant in open reaches. As with algae, macroinvertebrate diversity should be greater in forested reaches due to the greater diversity of microhabitats.

#### 4.8 FISH

Fish community composition and biomass were determined at each stream reach during late fall based on removal (depletion) sampling at blocked portions of each reach using a backpack electroshocker. Blocked sampling areas were centered within each reach, and extended 14 times the channel width or a minimum of 40 meters in length. Fishes from each reach were identified to species, measured, and weighed. Population, species diversity, and biomass metrics were calculated and used to evaluate relationships with habitat types, riparian vegetation, and urban development within each watershed.

Preliminary results suggest greater total biomass and number of individuals in non-forested stream reaches than in forested reaches (Table I). This is consistent with ongoing work in relatively undisturbed watersheds (Horwitz et al. 1998) which has shown greater abundance and biomass of most species in unmowed, ungrazed meadow reaches compared to forested reaches. Marked differences in species composition between forested and non-forested reaches were not seen, although differences in occurrence of several species were noted along the urbanization gradient. The difference in species richness between forested and non-forested reaches decreased slightly, but not significantly with increased urbanization in watersheds. Future analyses will include an examination of fish production and population size structure at each of the study reaches.

### 5. Summary and Future Analyses

An integrated, multi-disciplinary research project is being conducted to assess the benefits of riparian reforestation on stream ecosystems in urban watersheds in southeastern Pennsylvania. Project results will provide policy makers with key information about the ecological benefits of riparian forests as well as methods for targeting, prioritizing and, where necessary, supplementing riparian reforestation efforts in urban watersheds. The study is based on sampling of physical, chemical, and biological attributes at paired forested and non-forested reaches, where forested reaches are considered representative of restored riparian conditions, and non-forested reaches representative of pre-restoration, disturbed conditions. This paper presents preliminary results from the first year of fieldwork. Sampling and analysis at additional sites will continue through December 2000.

Future analyses will include the development of a reach-scale, numerical model of river channel evolution to predict the influence of vegetation on fluvial

processes. Empirical models relating ecosystem attributes to riparian condition and indices of urban disturbance will also be developed using multivariate statistical techniques. The resulting models will allow for a screening-level prioritization of riparian reforestation sites, and will assist federal, state, and local agencies in allocating resources to achieve restoration goals.

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